



Ames Research Center

Eclipse of the Floating Orbs

Controlling Robots on the International Space Station

DW Wheeler

Intelligent Robotics Group

Converge – March 20, 2017

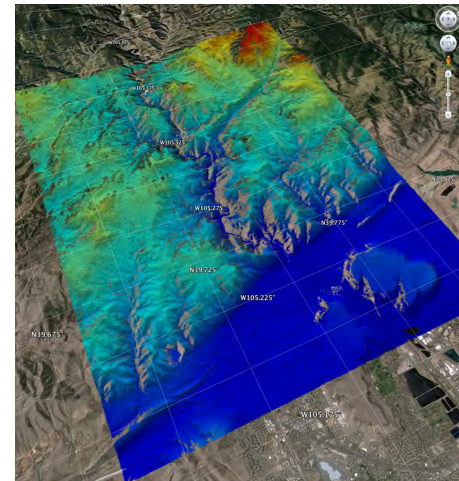
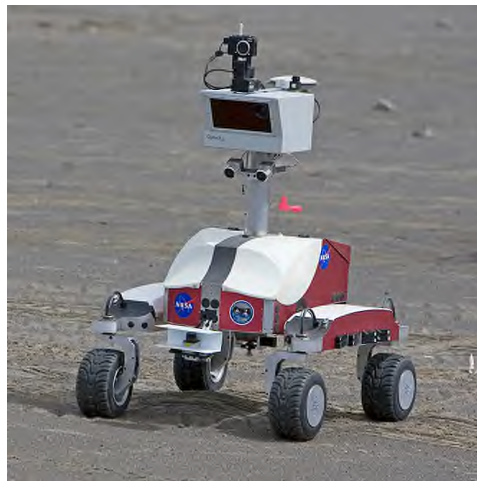
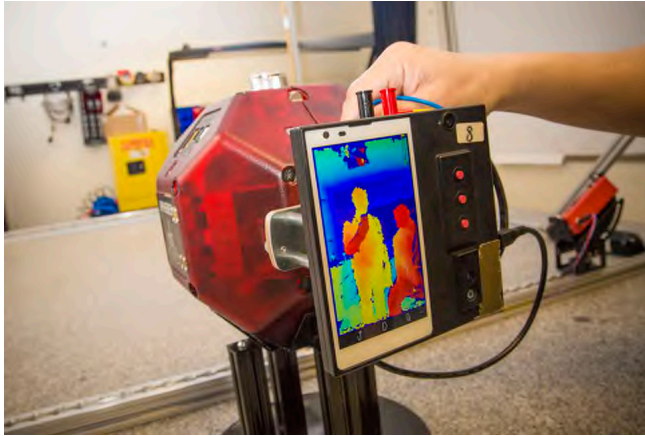


irg.arc.nasa.gov

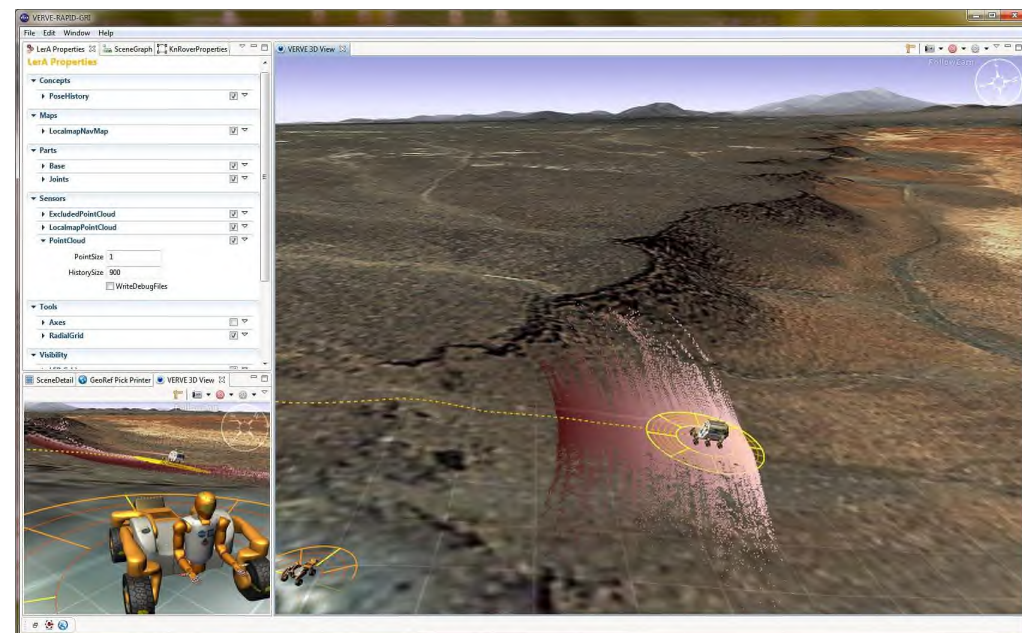
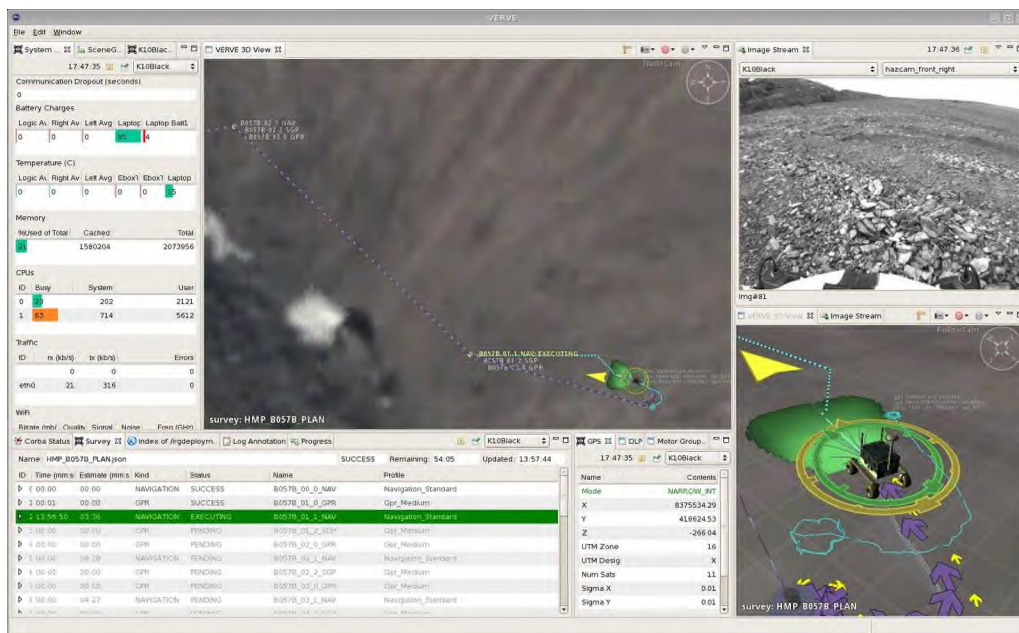
Contents

- Background
- Astrobees
- The Astrobees Control Station
 - Plan Editor
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- Videos

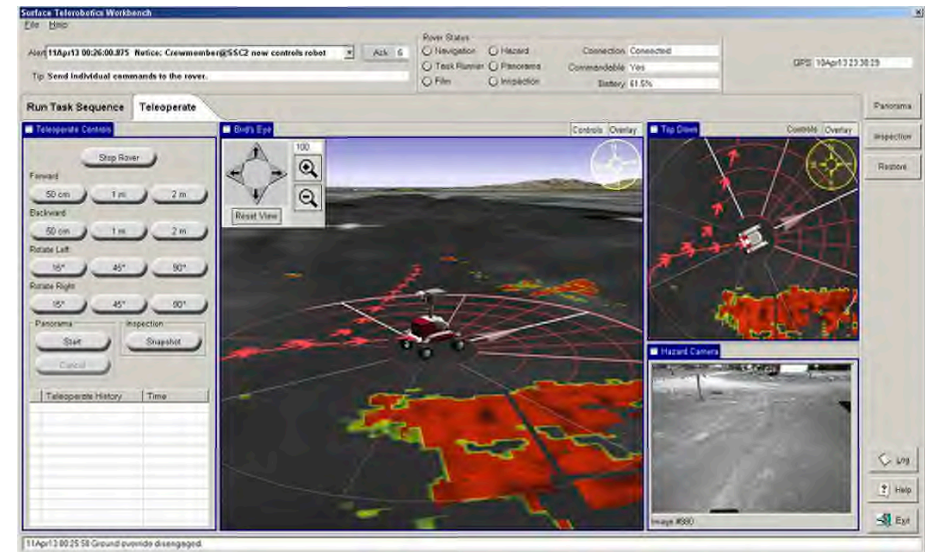
Intelligent Robotics Group



Visual Environment for Remote Virtual Exploration



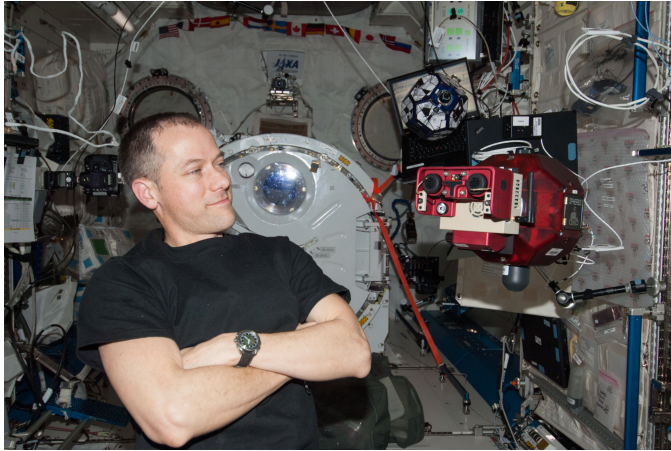
VERVE on ISS



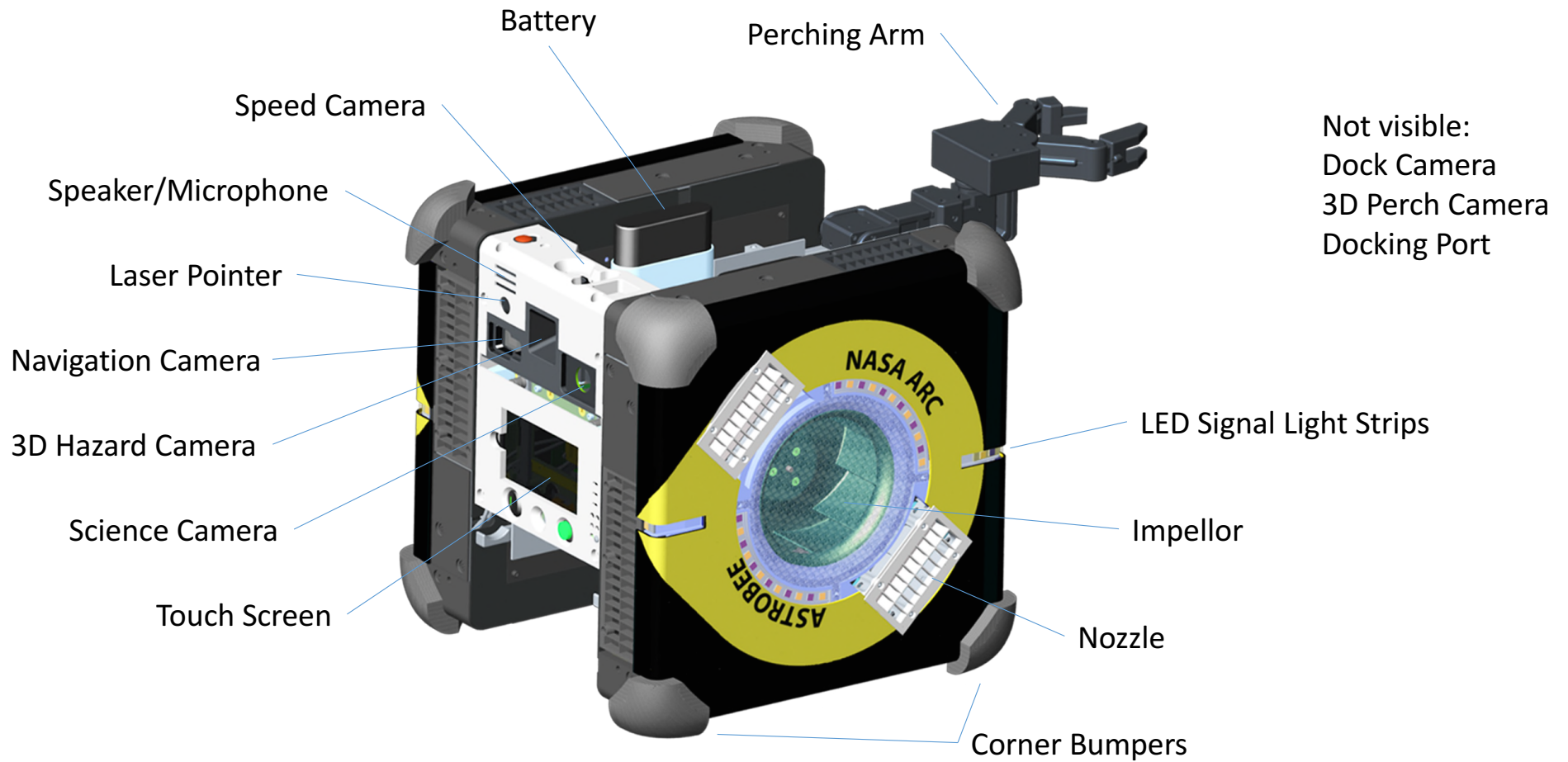
SPHERES



SPHERES Payloads



Astrobee



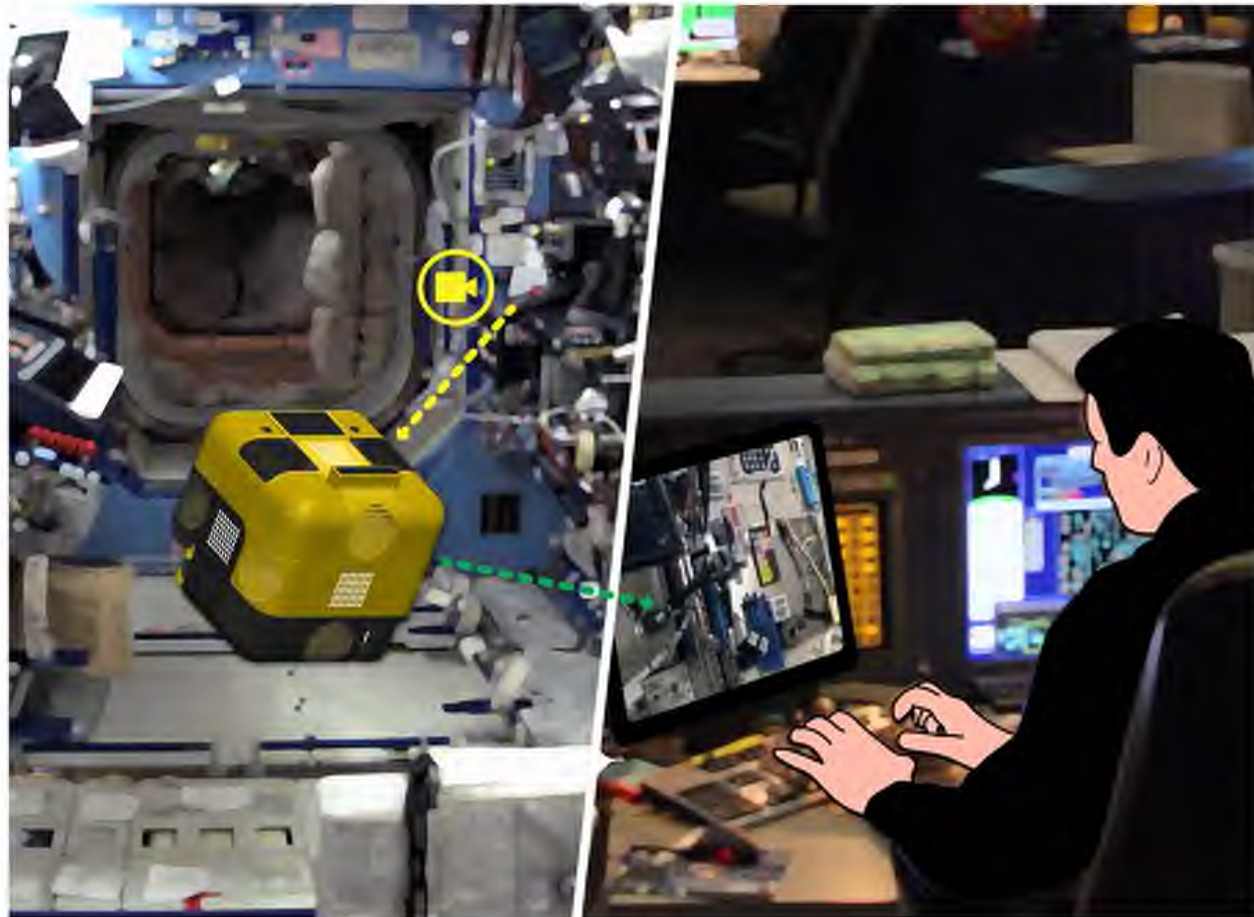
Dock and Resupply



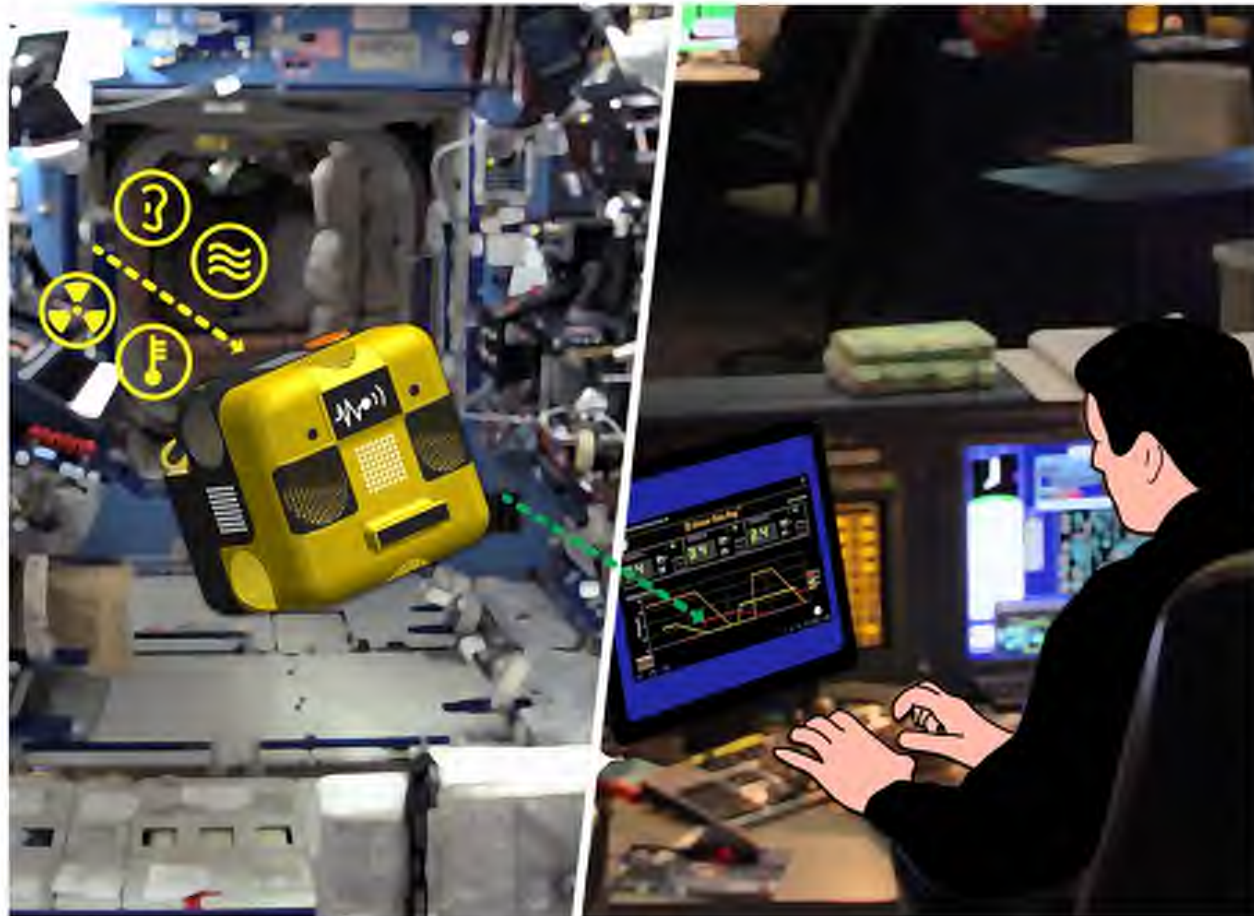
Zero Gravity Research Facility



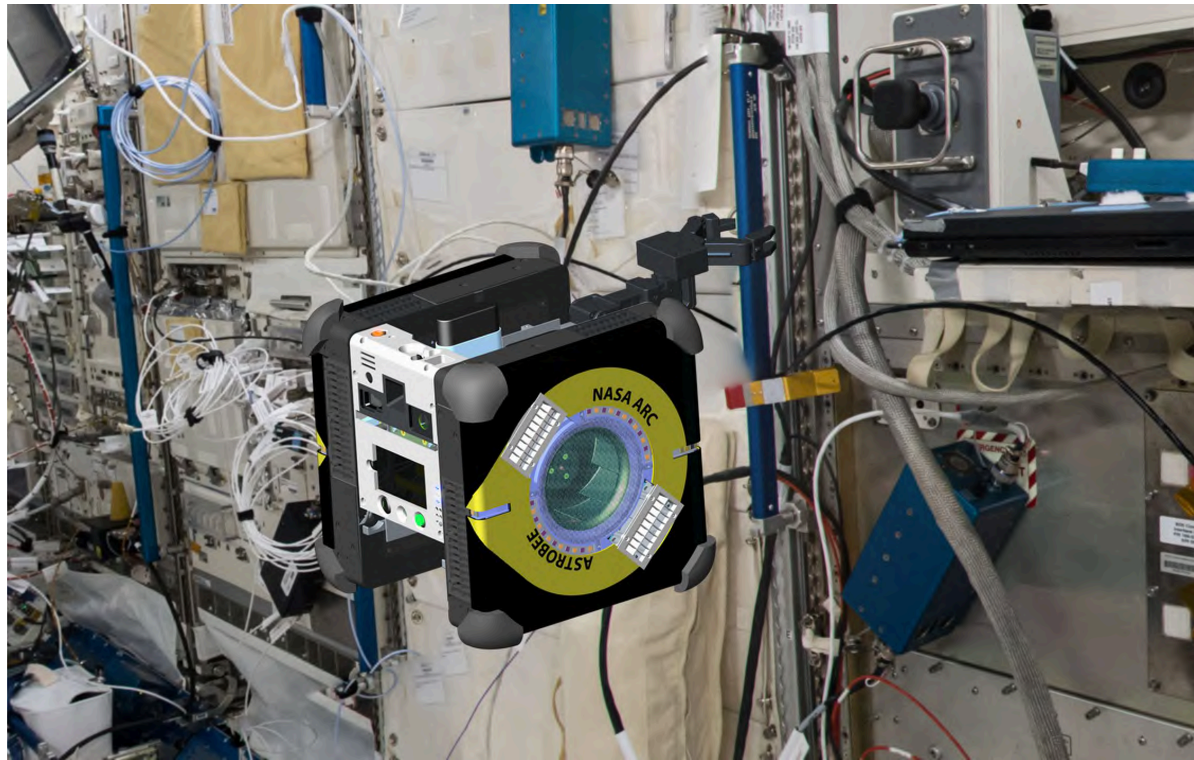
Mobile Camera



Mobile Sensor



How to Control Astrobeee?



Astrobee Control Station(s)

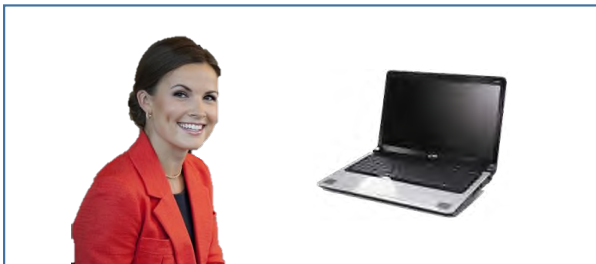
Function	Astronauts	Flight Controllers	Astrobee Engineering and Guest Researchers
Create Plans		X	X
Run Plans	X	X	X
Teleoperate	X	X	X
Run Guest Research	X		X
Engineering Tools			X

Astronauts



ISS

Flight Controllers



Mission Control

Astrobee Engineering



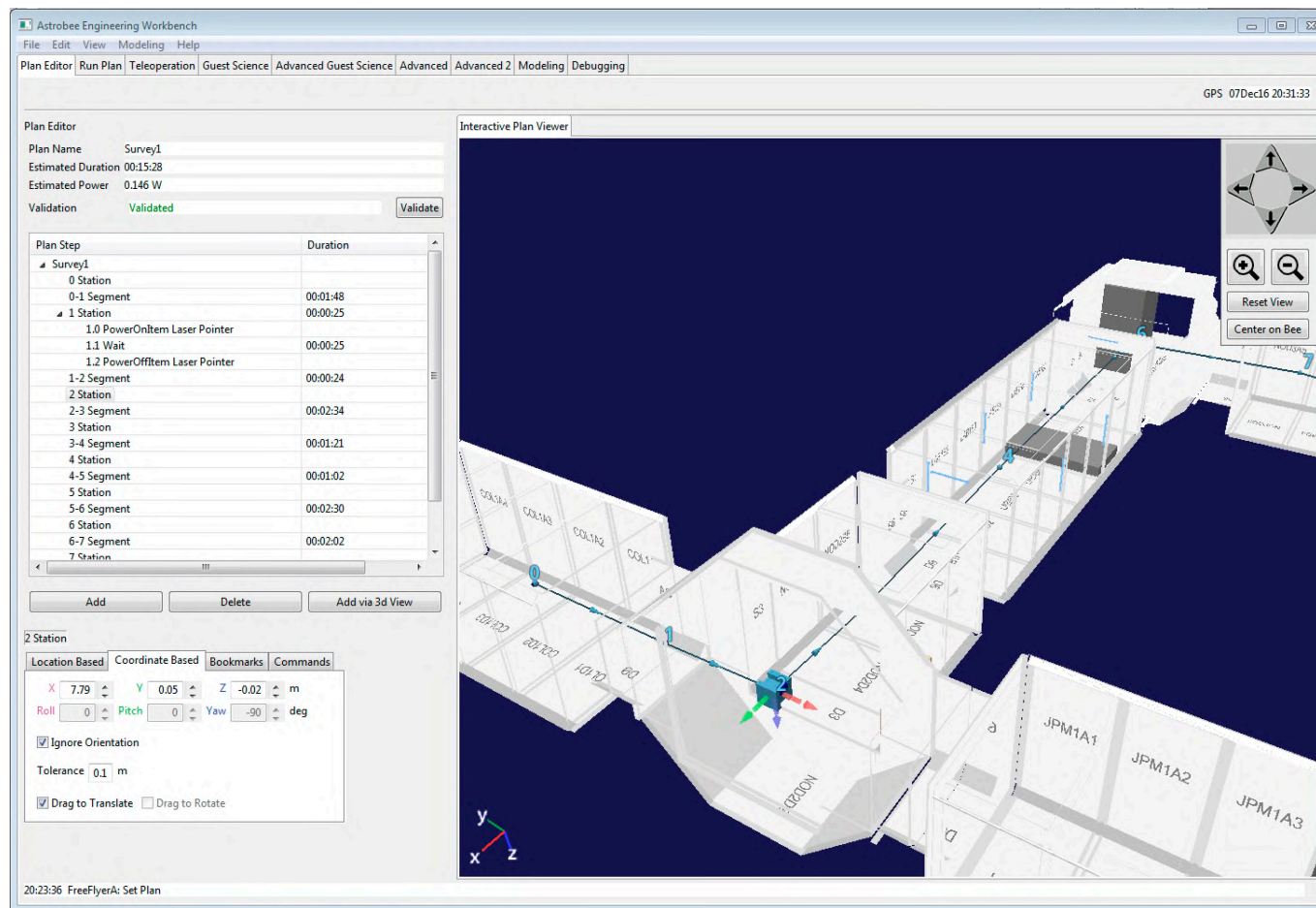
ARC

Guest Researchers

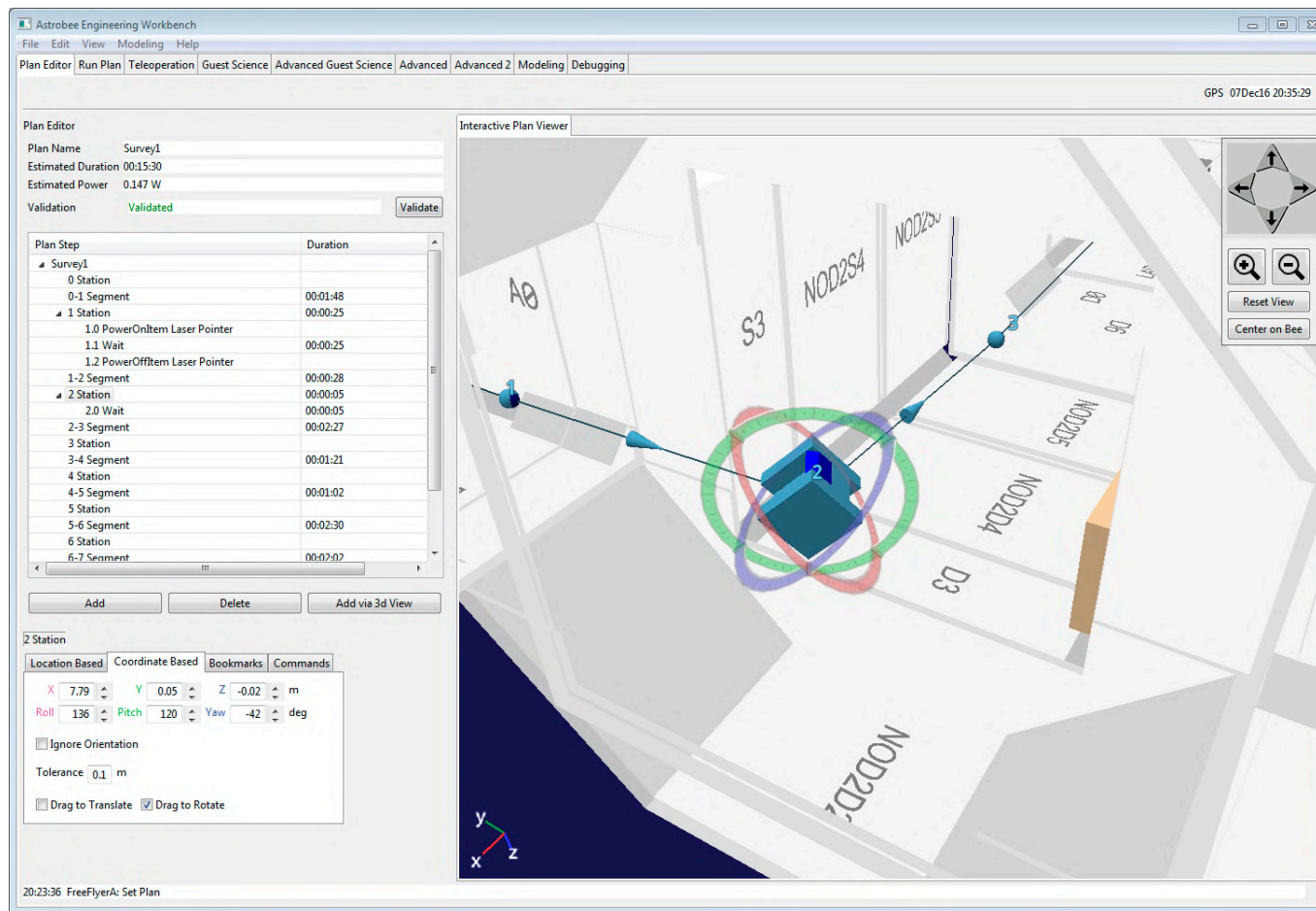


Universities

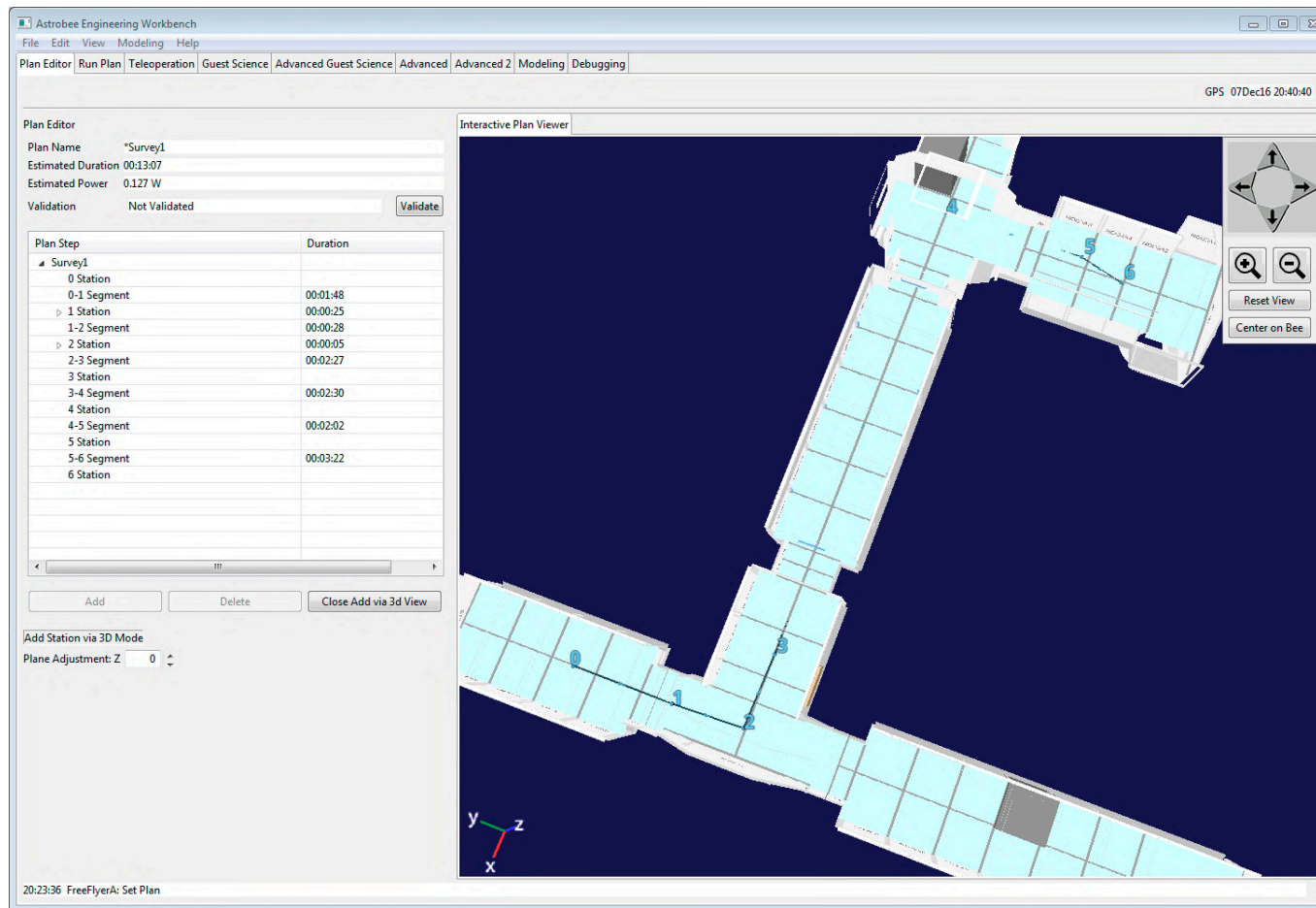
Plan Editor



Plan Editor



Plan Editor



Plan Validation

Astrobe Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

GPS 07Dec16 19:58:50

Plan Editor

Plan Name *Survey1
Estimated Duration 00:05:39
Estimated Power 0.109 W
Validation Not Validated **Validate**

Plan Step	Duration
Survey1	
0 Station	
0-1 Segment	00:00:51
1 Station	00:00:25
1-2 Segment	00:00:28
2 Station	
2-3 Segment	00:01:01
3 Station	
3-4 Segment	00:00:46
4 Station	
4-5 Segment	00:00:49
5 Station	
5-6 Segment	00:01:00
6 Station	
6-7 Segment	00:00:18
7 Station	
7-8 Segment	00:00:11
8 Station	

6 Station

Location Based Coordinate Based Bookmarks Commands

X -6.23 Y -0.00 Z 0.04 m
Roll 0 Pitch 0 Yaw -90 deg
☐ Ignore Orientation
Tolerance 0.1 m
☒ Drag to Translate ☐ Drag to Rotate

Interactive Plan Viewer

Validation Failed

Potential collision in Segment 6-7. Please move Station 6 or Station 7.

OK

00:00:00 Message goes here

Running Plans

Astrobee Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

FreeFlyerA Comm ● Control DW@DW-Windows7-32 Batt 98 Docking Station ● GPS 23Feb17 17:16:40

Health and Status Details

Operating State	Ready
Mobility State	Stopped
Operating Limits	Default_Safeguard
Plan	Survey1
Plan Status	Paused

Initialization

Hibernate

Grab Control

Robot Commanding

File ... C:\Users\DW\Desktop\FPlans\Survey1.fplan

Plan Valid

Load Run Pause Skip Step

Description

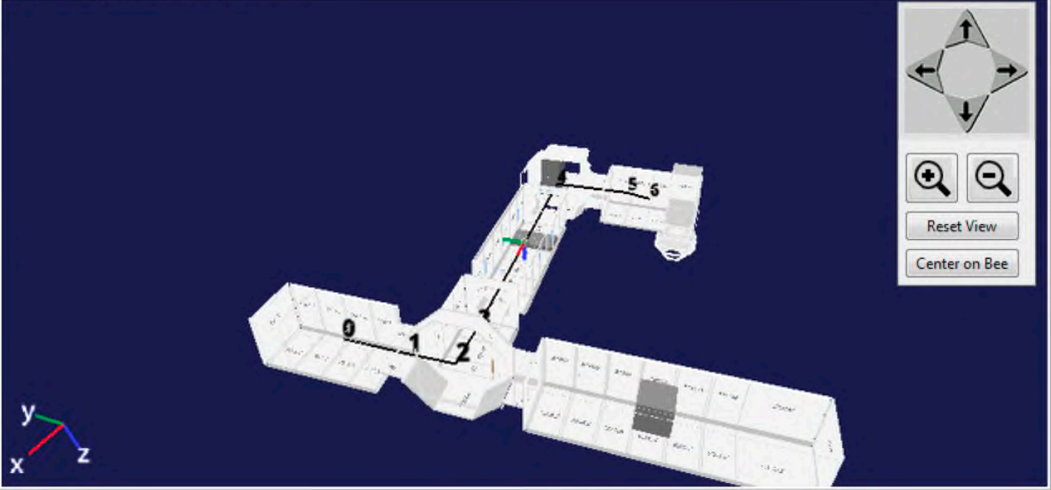
Survey European Lab and US Lab

Plan

Total Elapsed Time 00:00:00

Plan Step	Duration	Success
Survey1		
0 Station		
0-1 Segment		
1 Station		
1.0 PowerOn1ten		
1.1 Wait		
1.2 PowerOff1ten		
1-2 Segment		
2 Station		
2.0 Wait		
2-3 Segment		
3 Station		
3-4 Segment		
4 Station		
4-5 Segment		
5 Station		
5-6 Segment		
6 Station		

Live Telemetry Live Images Science Camera



17:15:26 FreeFlyerA: Set Plan

Running Plans

Astrobee Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

FreeFlyerA Comm ● Control DW@DW-Windows7-32 Batt 98 Docking Station ● GPS 23Feb17 17:18:04

Health and Status Details

Operating State	Plan Execution
Mobility State	Flying
Operating Limits	Default_Safeguard
Plan	Survey1
Plan Status	Executing

Initialization

Hibernate

Robot Commanding

File ... C:\Users\DW\Desktop\FPlans\Survey1.fplan

Plan Valid

Load Run Pause Skip Step

Description


Survey European Lab and US Lab

Plan

Total Elapsed Time 00:00:50

Plan Step	Duration	Success
Survey1		
0 Station		Complete
0-1 Segment	00:01:48	Complete
1 Station		Complete
1.0 PowerOnIten		Complete
1.1 Wait	00:00:25	Complete
1.2 PowerOffIten		Complete
1-2 Segment	00:00:28	Complete
2 Station		Complete
2.0 Wait	00:00:05	Complete
2-3 Segment		
3 Station		
3-4 Segment		
4 Station		
4-5 Segment		
5 Station		
5-6 Segment		
6 Station		

Live Telemetry Live Images Science Camera



17:18:00 FreeFlyerA: Run Plan Pending ...

Running Plans

Astrobe Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

FreeFlyerA Comm ● Control DW@DW-Windows7-32 Batt 98 Docking Station ● GPS 23Feb17 17:18:04

Health and Status

Operating State	Plan Execution
Mobility State	Flying
Operating Limits	Default_Safeguard
Plan	Survey1
Plan Status	Executing

Plan

Total Elapsed Time 00:00:50

Plan Step	Duration	Success
Survey1		
0 Station		Complete
0-1 Segment	00:01:48	Complete
1 Station		Complete
1.0 PowerOnIen		Complete
1.1 Wait	00:00:25	Complete
1.2 PowerOffIen		Complete
1-2 Segment	00:00:28	Complete
2 Station		Complete
2.0 Wait	00:00:05	Complete
2-3 Segment		
3 Station		
3-4 Segment		
4 Station		
4-5 Segment		
5 Station		
5-6 Segment		
6 Station		

Robot Commanding


File ... C:\Users\DW\Desktop\FPlans\Survey1.fplan

Plan Valid

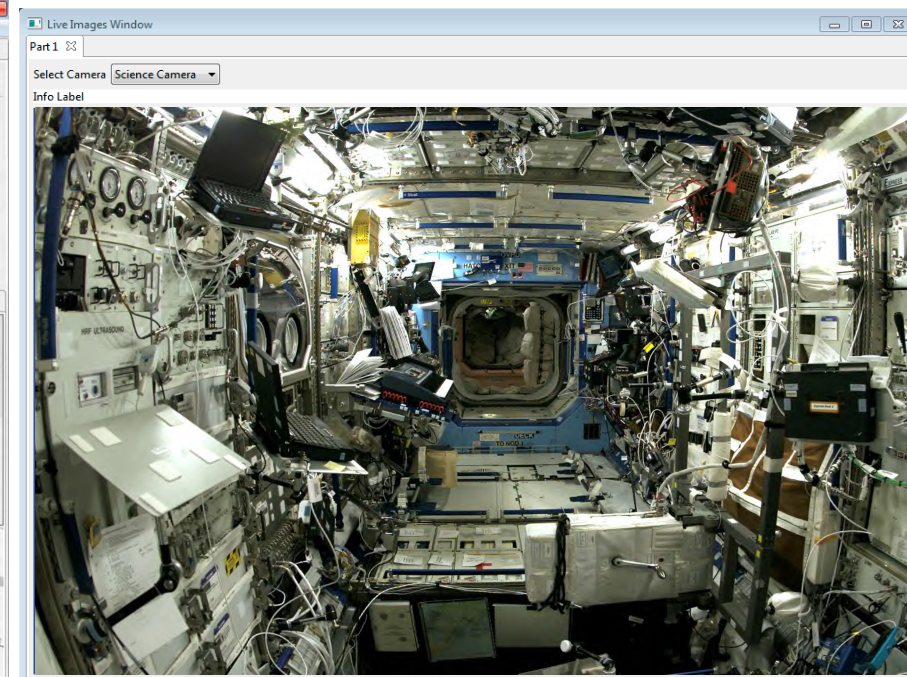
Grab Control Load Run **Pause** Skip Step

Description
Survey European Lab and US Lab

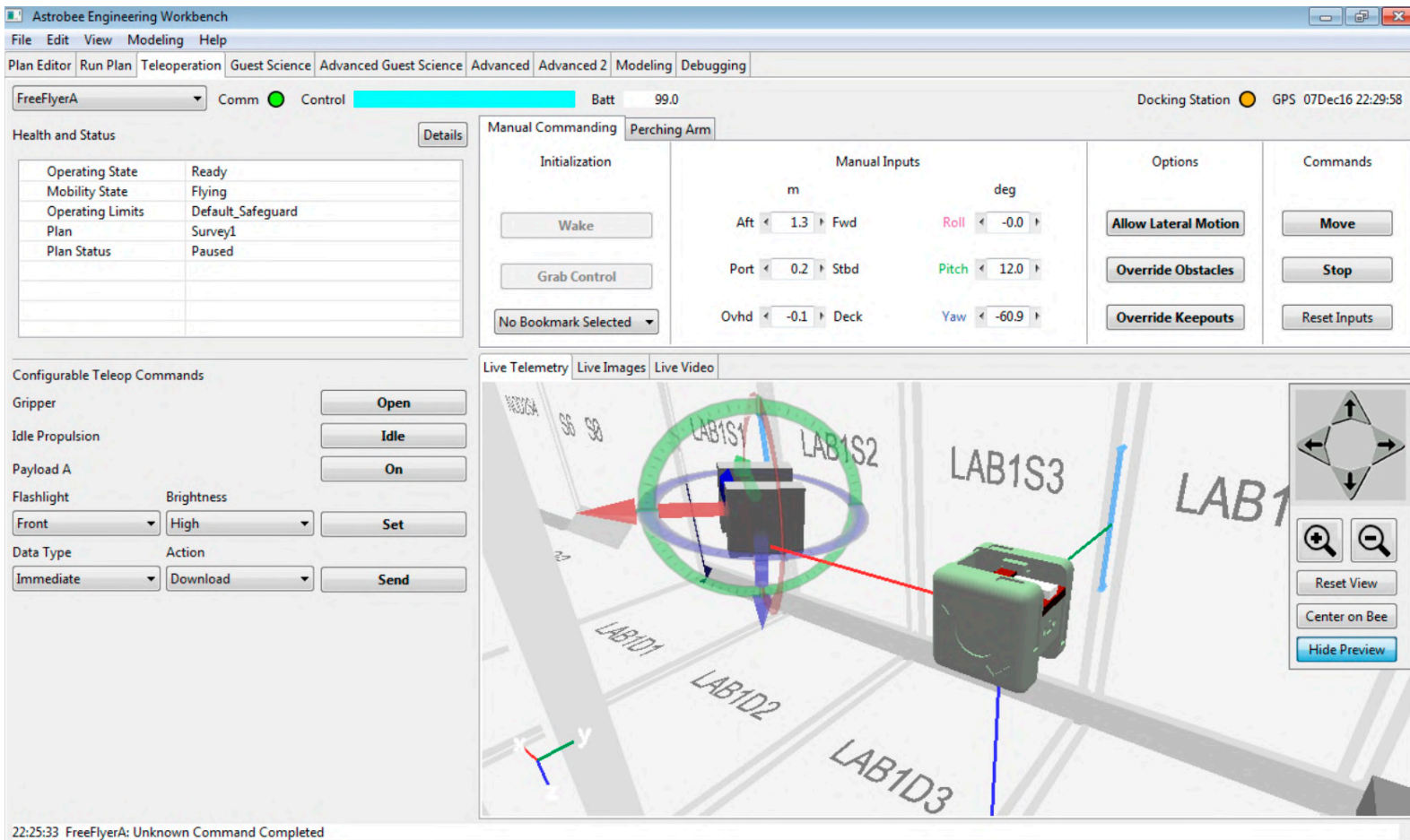
Live Telemetry Live Images Science Camera



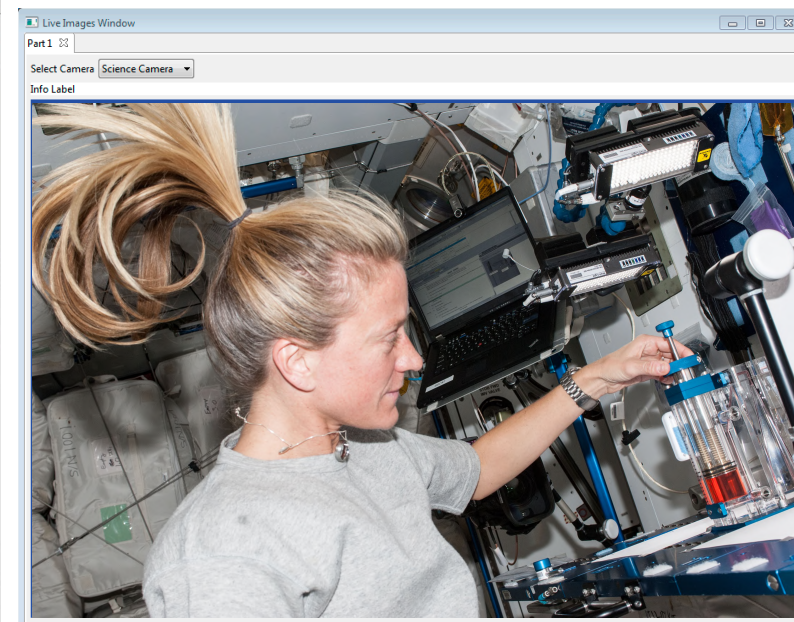
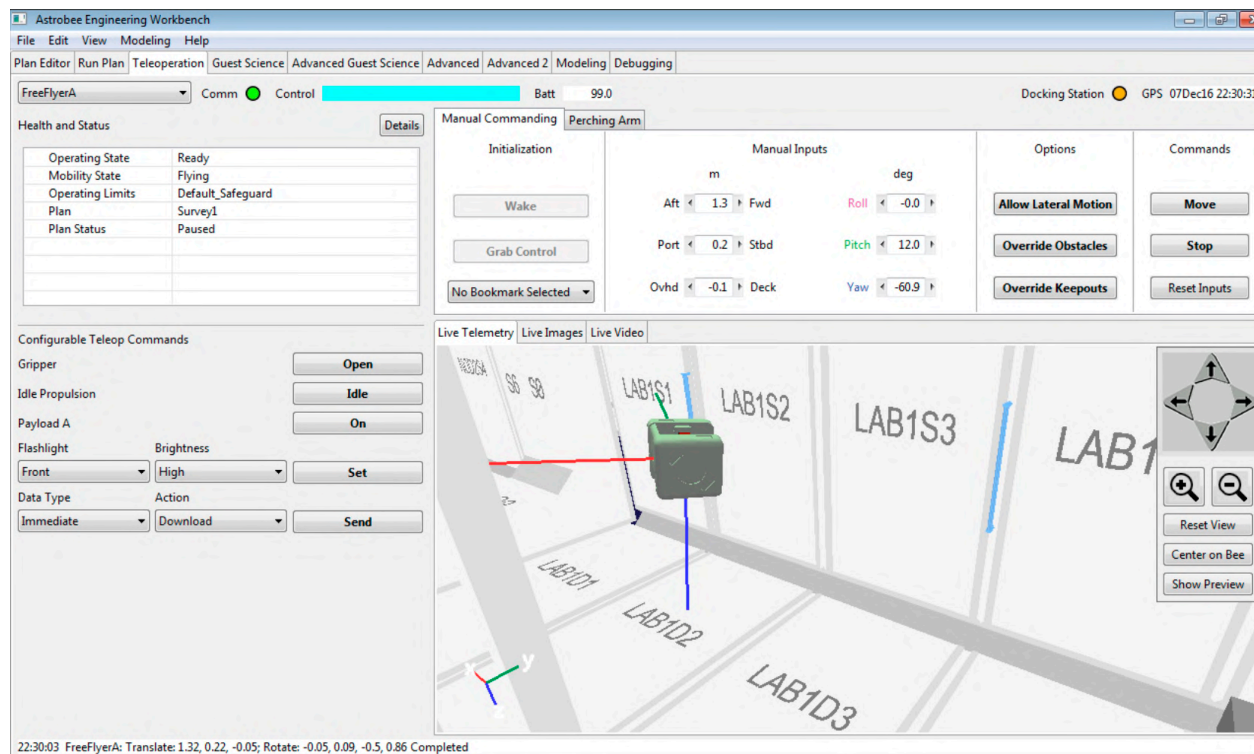
17:18:00 FreeFlyerA: Run Plan Pending ...



Teleoperation



Teleoperation



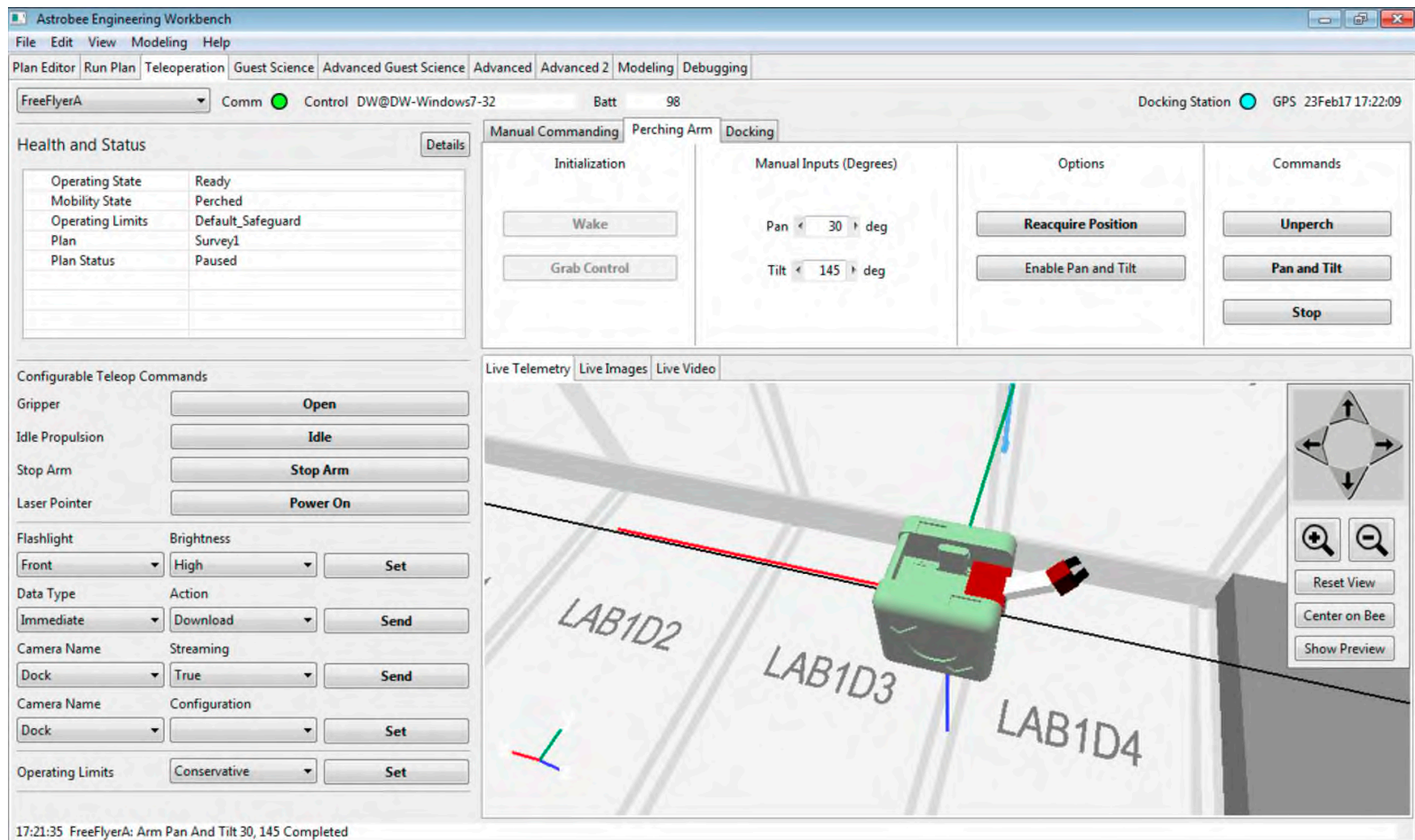
Teleoperation

The screenshot displays the Astrobee Engineering Workbench interface, which is used for teleoperating the Astrobee robot. The interface is divided into several sections:

- Top Bar:** Includes the title "Astrobee Engineering Workbench" and a menu bar with "File", "Edit", "View", "Modeling", and "Help". Below the menu bar are tabs for "Plan Editor", "Run Plan", "Teleoperation", "Guest Science", "Advanced Guest Science", "Advanced", "Advanced 2", "Modeling", and "Debugging".
- Health and Status:** A section on the left showing the robot's status. It includes a dropdown menu for "FreeFlyerA", a "Comm" status indicator (green dot), a "Control" status indicator (green dot), a "Batt" level of 99.0, and a "Docking Station" status indicator (yellow dot). The "GPS" location is "07Dec16 22:40:21".
- Manual Commanding:** A section in the center-right for manual control. It includes a "Perching Arm" tab, "Initialization" buttons ("Wake", "Grab Control", "No Bookmark Selected"), and "Manual Inputs" for "Aft", "Fwd", "Port", "Stbd", "Ovhd", and "Deck". The inputs are displayed in meters (m) and degrees (deg). The "Roll" input is -0.0, "Pitch" is 0.0, and "Yaw" is -44.4.
- Options and Commands:** A section on the right with "Options" (Allow Lateral Motion, Override Obstacles, Override Keepouts) and "Commands" (Move, Stop, Reset Inputs). A "Potential collision" warning is visible.
- Configurable Teleop Commands:** A section on the left for configuring teleoperation commands. It includes buttons for "Open", "Idle", and "On", and a "Set" button. The "Flashlight" is set to "Front" and "High", and the "Data Type" is set to "Immediate" and "Download".
- Live Telemetry:** A section at the bottom left showing "Live Telemetry", "Live Images", and "Live Video".
- 3D Simulation:** A large 3D simulation window on the right showing the Astrobee robot in a simulated environment. The robot is a small orange cube with a green circular motion path around it. The environment includes a grid and labels for "LAB1S1", "LAB1S2", "LAB1S3", "LAB1S4", "LAB1D3", and "LAB1D4". A red line indicates the robot's current position and orientation.

At the bottom of the interface, a status bar displays the time "22:34:32" and the command "FreeFlyerA: Translate: 1.32, 0.22, -0.05; Rotate: 0, 0, 0, 1 Completed".

Teleoperation



Multiple Astrobee Control

Astrobee Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

GPS 07Dec16 23:02:46

Astrobee Selection and Status

	Control	Batt	Summary	Plan	Plan Status	Plan Step	APK	APK Status	Health
<input checked="" type="checkbox"/>	FreeFlyerA	DW@DW-Windows7-32	99.0	Survey2	Idle	1 Station	Geiger Counter	Idle	
<input type="checkbox"/>	FreeFlyerB	nobody	99.0	Survey2-parallel	Idle	1 Station	Geiger Counter	Idle	
<input type="checkbox"/>	FreeFlyerC								

Commanding for FreeFlyerA

Wake Grab Control

Plans

Load

Run Stop

APKs

Start Stop

Manual Commanding

APK Template

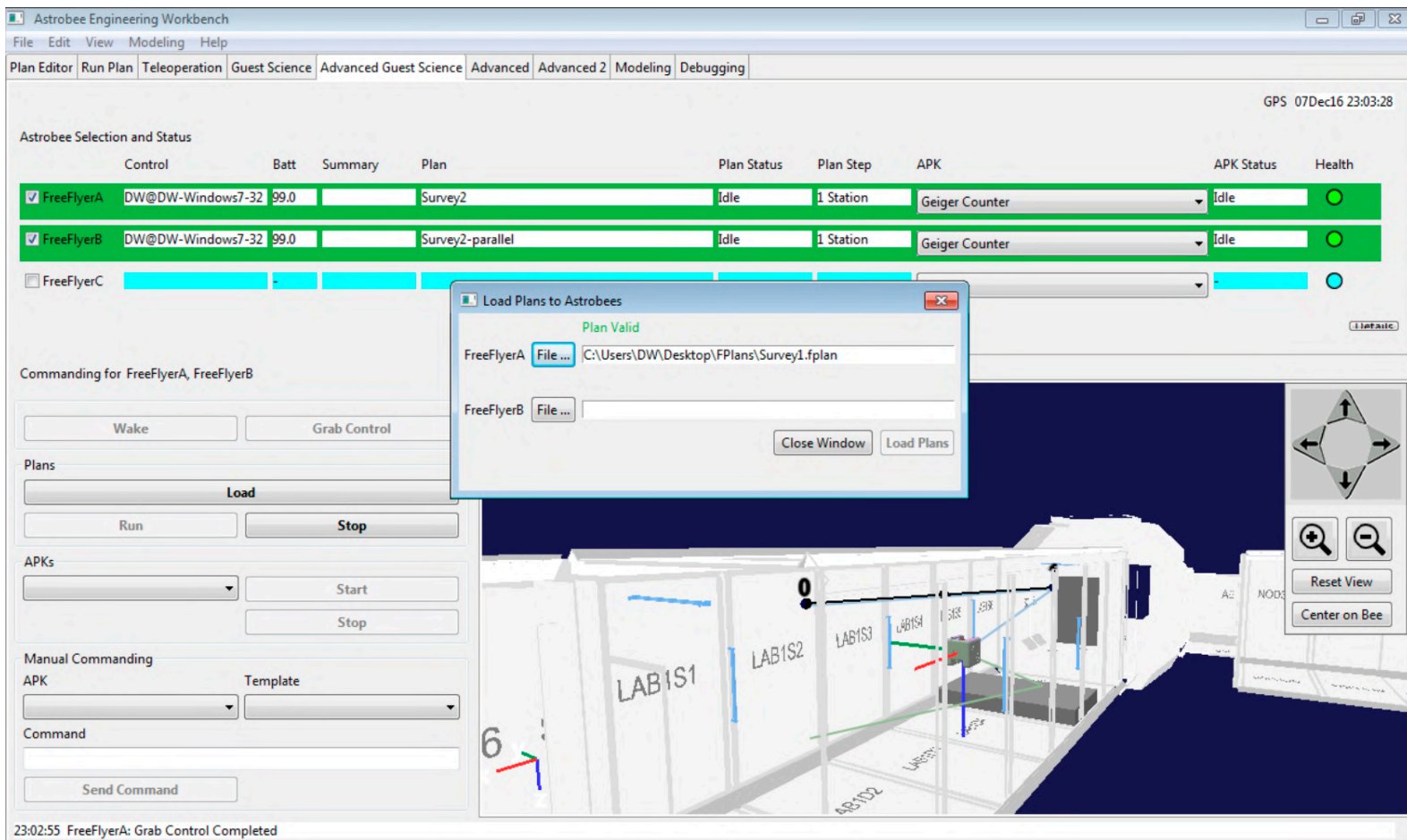
Command

Send Command

23:02:12 FreeFlyerA: Grab Control Completed

Live Telemetry Live Images Science Camera Guest Science Telemetry

Multiple Astrobee Control



Multiple Astrobee Control

Astrobee Engineering Workbench

File Edit View Modeling Help

Plan Editor Run Plan Teleoperation Guest Science Advanced Guest Science Advanced Advanced 2 Modeling Debugging

GPS 07Dec16 23:10:22

Astrobee Selection and Status

	Control	Batt	Summary	Plan	Plan Status	Plan Step	APK	APK Status	Health	
<input checked="" type="checkbox"/>	FreeFlyerA	DW@DW-Windows7-32	99.0		Survey2	Idle	1 Station	Geiger Counter	Running	
<input checked="" type="checkbox"/>	FreeFlyerB	DW@DW-Windows7-32	99.0		Survey2-parallel	Idle	1 Station	Geiger Counter	Running	
<input type="checkbox"/>	FreeFlyerC									

Commanding for FreeFlyerA, FreeFlyerB

Wake Grab Control

Plans

Load

Run Stop

APKs

Start Stop

Manual Commanding

APK Turbo Template Mode Power+Duration

Command

command body for command PD

Send Command

23:08:24 FreeFlyerB: Start Guest Science gov.nasa.arc.irg.astrobee.GrapplingHook

Live Telemetry Live Images Science Camera Guest Science Telemetry

AstrobeeA

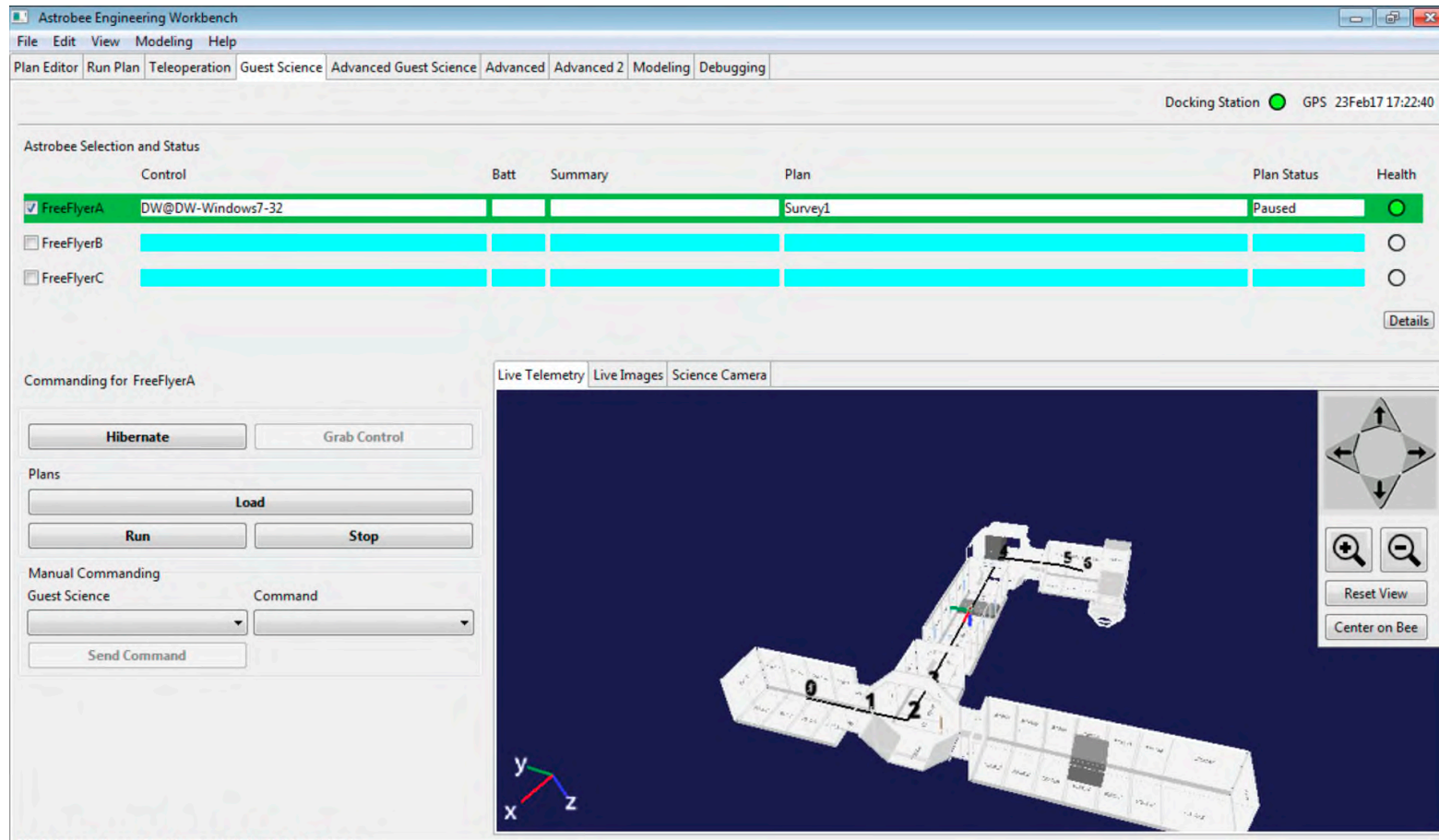
APK	STATUS
Turbo	Idle
Grappling Hook	Idle
Geiger Counter	Running

AstrobeeB

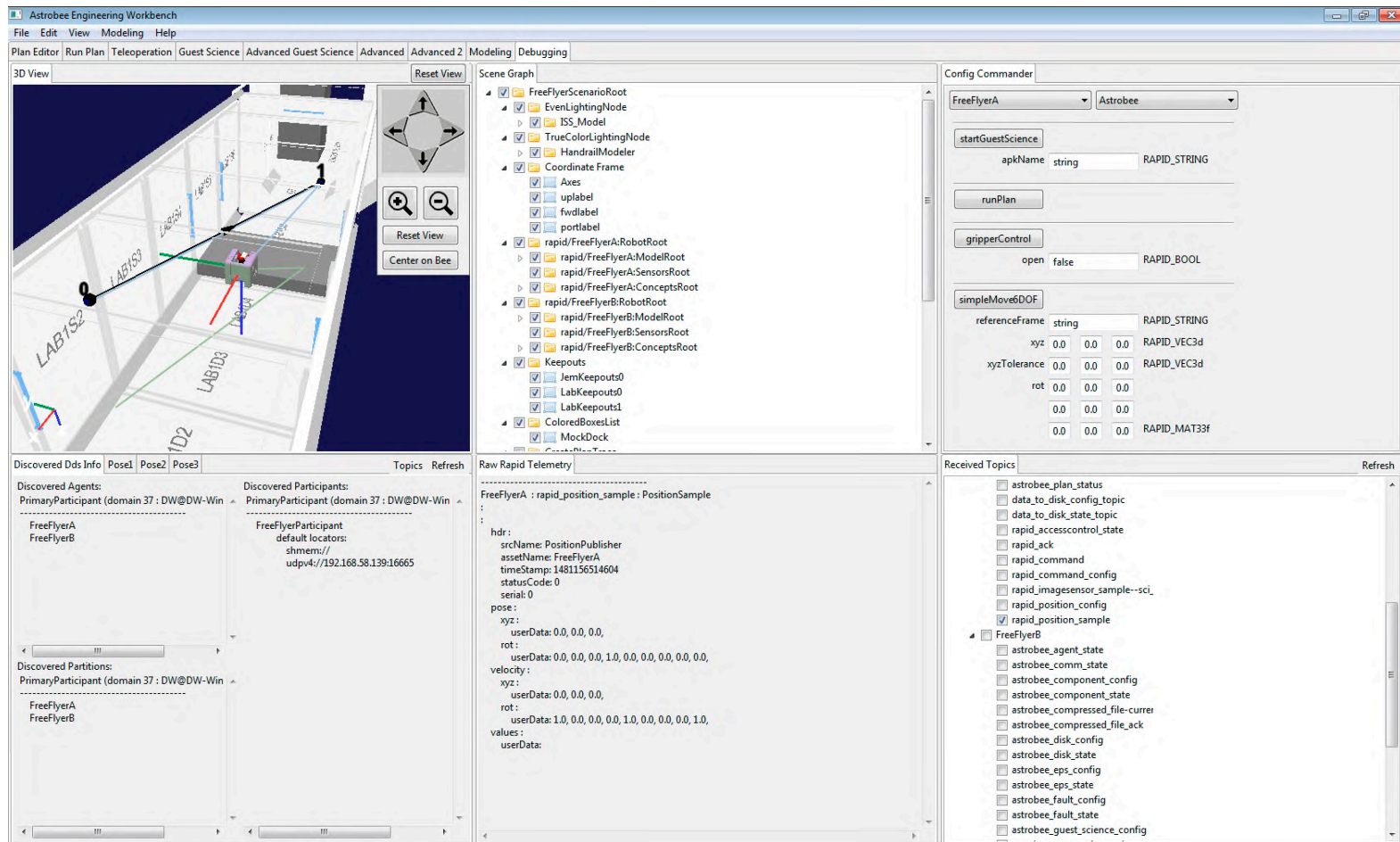
APK	STATUS
Geiger Counter	Running
Grappling Hook	Running
Turbo	Idle

APK	Topic	Label
Geiger Counter	Astrobee...	Status
Geiger Counter	Astrobee...	Data
Geiger Counter	Astrobee...	Info
Grappling Hook	Astrobee...	Status
Grappling Hook	Astrobee...	Data
Grappling Hook	Astrobee...	Info

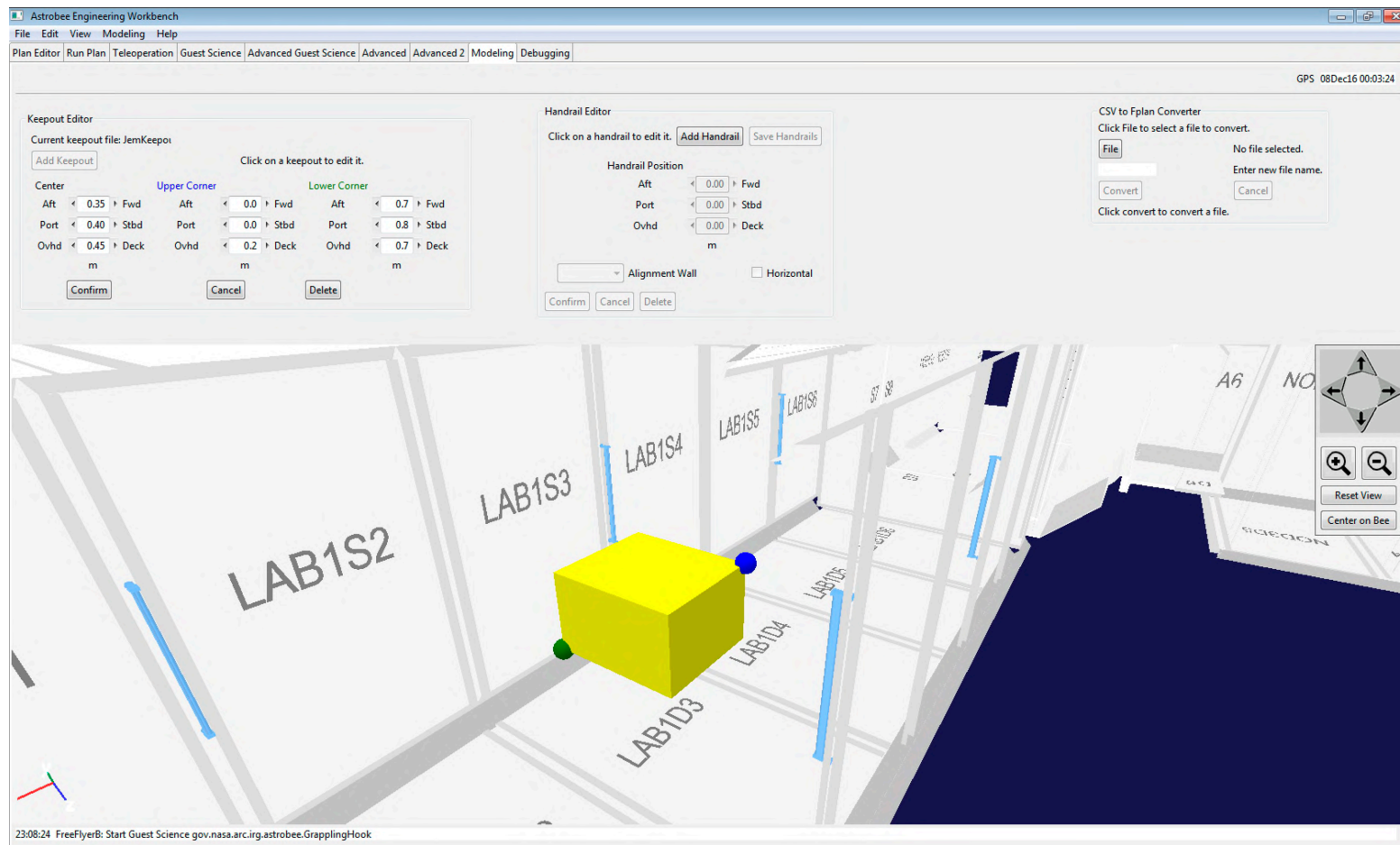
Multiple Astrobees Control - Crew



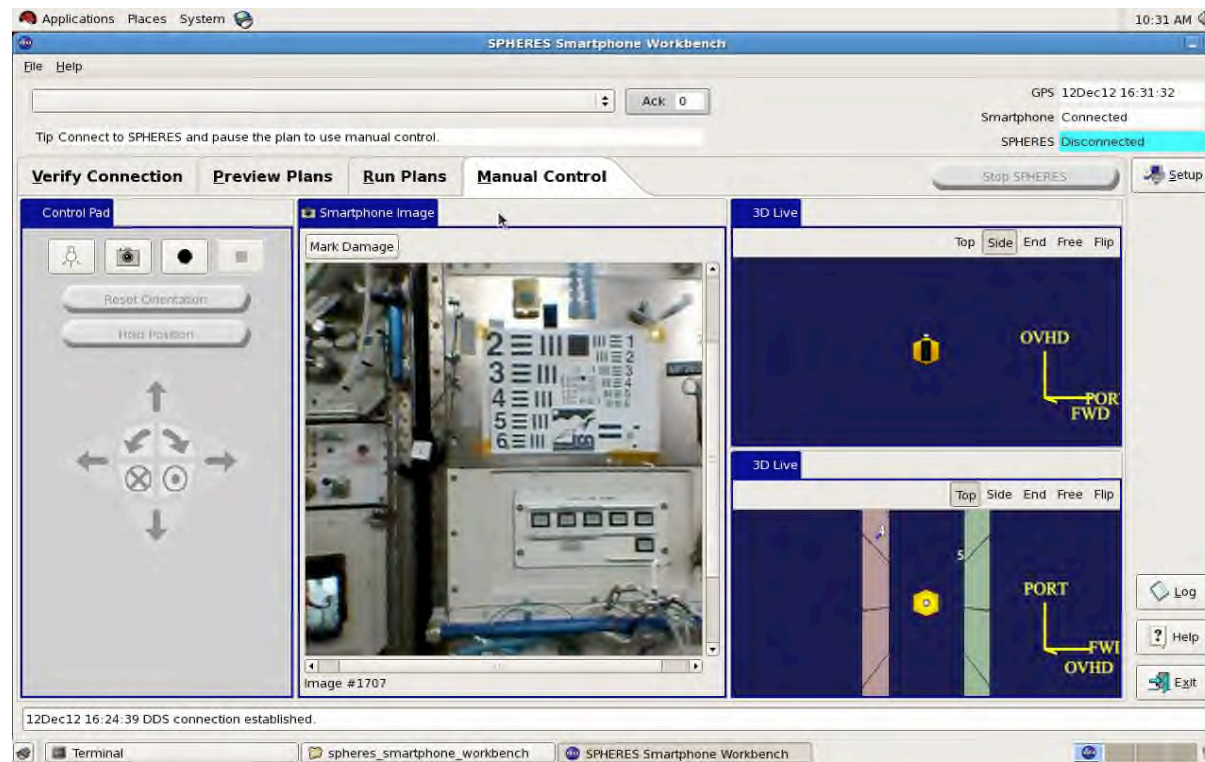
Engineering Tools - Debugging Panel



Engineering Tools - Modelling Panel



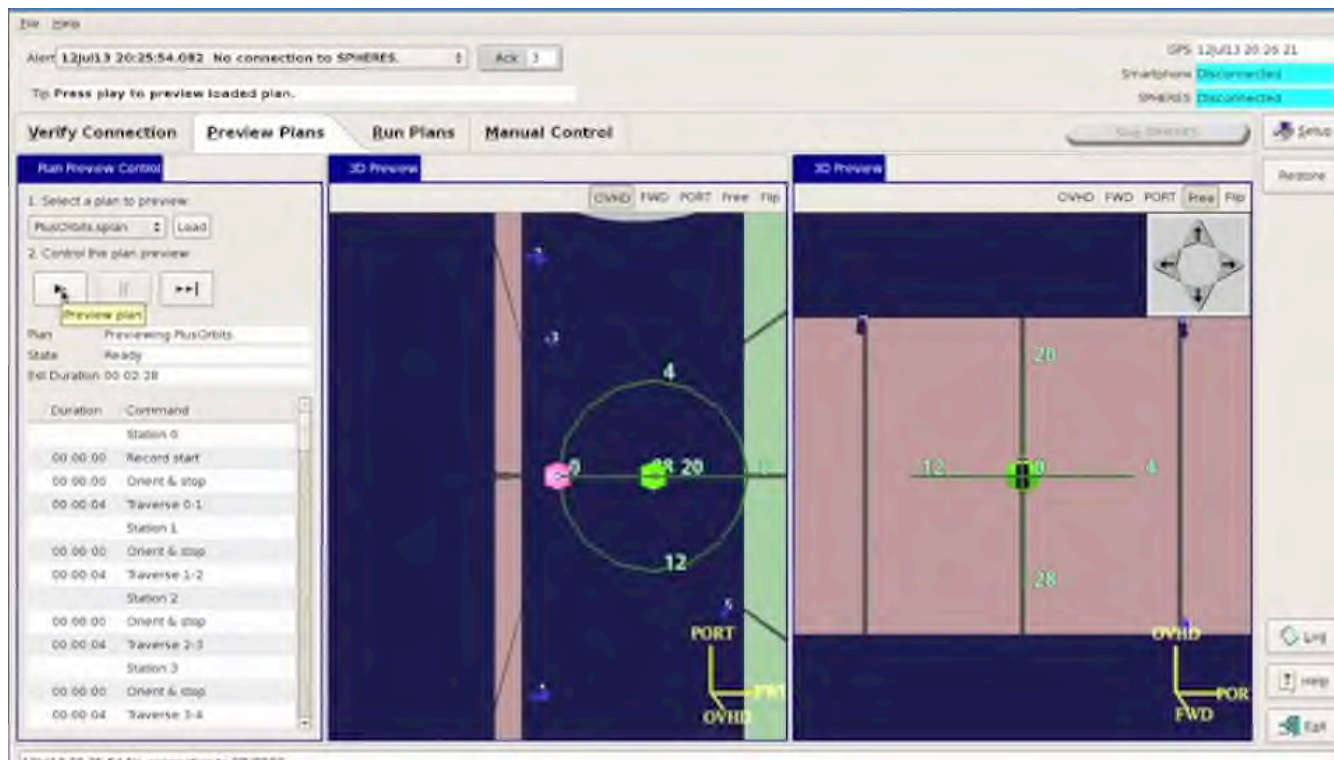
Video: SPHERES Controlled from Ground



Video: SPHERES in Space



Video: SPHERES Controlled from Space



Video: Astrobees Prototype Demo



Acknowledgements

- Astrobees Ground Data Systems Team
 - Ryan Goetz (JPL)
 - Past members: Connor Hitt, Jay Torres (JPL), Andy Martinez, Maria Bualat
 - Advisors: Jessica Martinez, Justin Cartledge (MSFC), Joe Fittipaldi (MSFC)
- VERVE Team
 - Mark Allan, Tamar Cohen, Eric Schafer
- Entire Astrobees Team
 - Terry Fong, Chris Provencher, Trey Smith, Lorenzo Fluckiger, Ted Morse, InWon Park, Jesse Fusco, Jonathan Barlow, Mike McIntyre, Hugo Sanchez, Earl Daley, Omar Talvera, Ernie Smith, and more

Questions?

Thank you!